

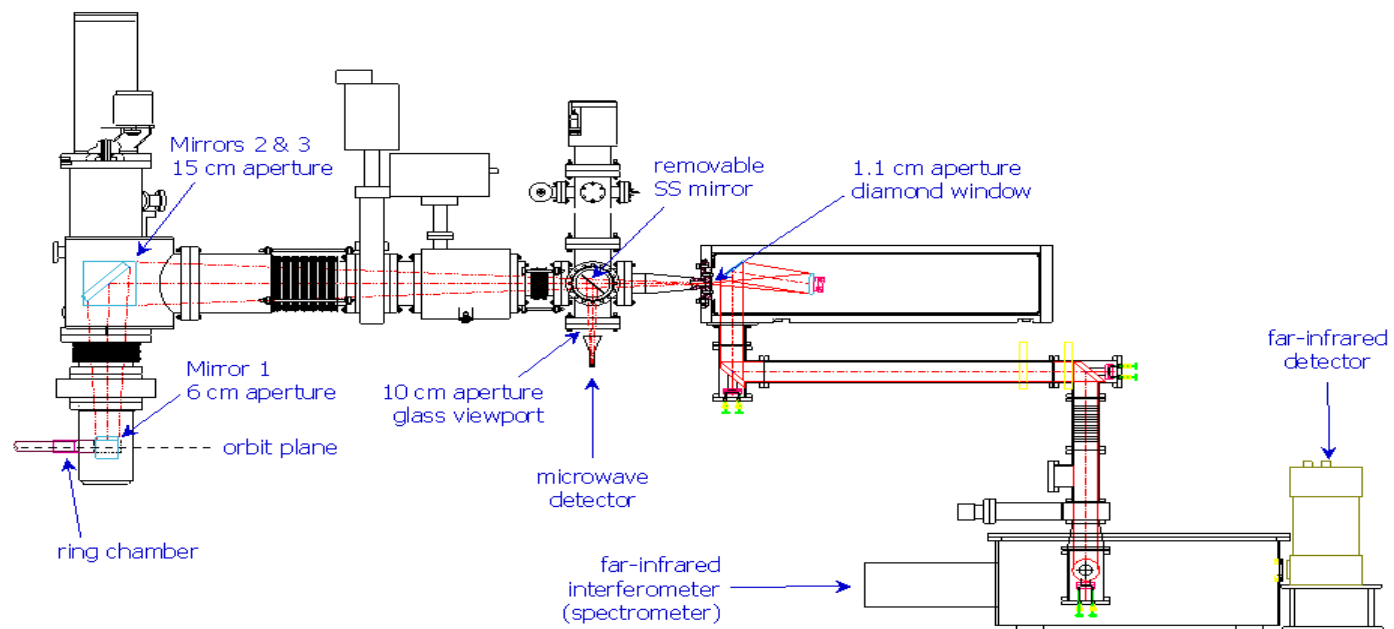
Coherent Microwave Synchrotron Radiation in the VUV Ring

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Content:

- **Detection of microwave beam signals 3 to 75 GHz**
- **CSR above and below shielding cut-off frequency**
- **Wakefield generation as signal source above waveguide cut-off**
- **Wakefield as source of CSR above shielding cut-off frequency**
- **Potential for steady state CSR ~100GHz to THz**

Layout of Microwave & FIR Beams

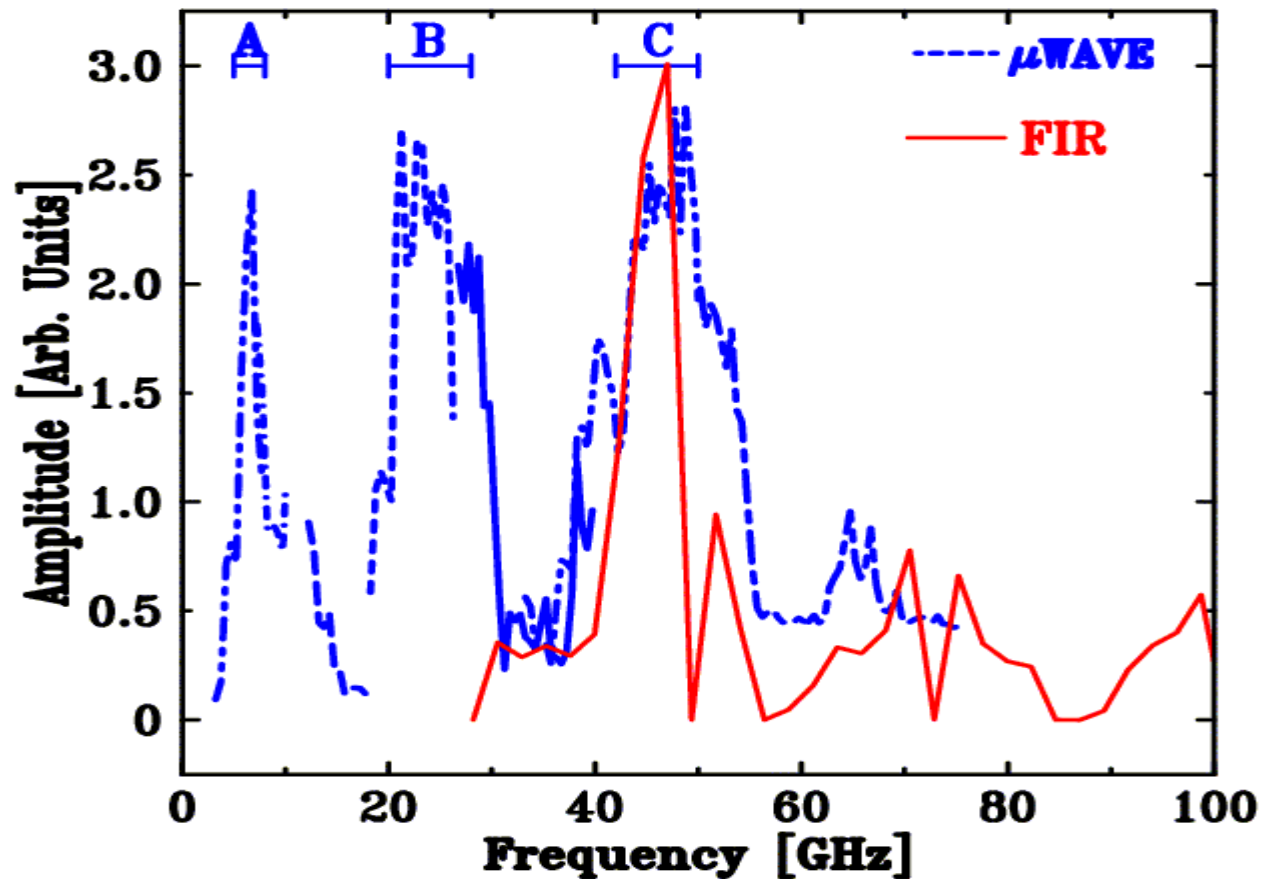


U12IR Beam to FIR Spectrometer

Microwave Detection

- Horn antenna collector to standard waveguide with length $>6X$ attenuation length (HPF)
- LPF for TE_{0,1} band selection yields linear E-field polarization
- RF spectrum analyzer with pre-selection filter
- Diode detectors for fast peak power measurements
- Diode and Thermocouple power detectors for reliable average power measurements

Microwave Signals from Beam



- RF spectrum analysis of 7 waveguide bands & FIR
- Observe 3 major peaks: A(5-8GHz), B(20-28GHz), C(42-50GHz)

Synchrotron Radiation Shielding

- EM Shielding due to vacuum chamber cut-off frequency:

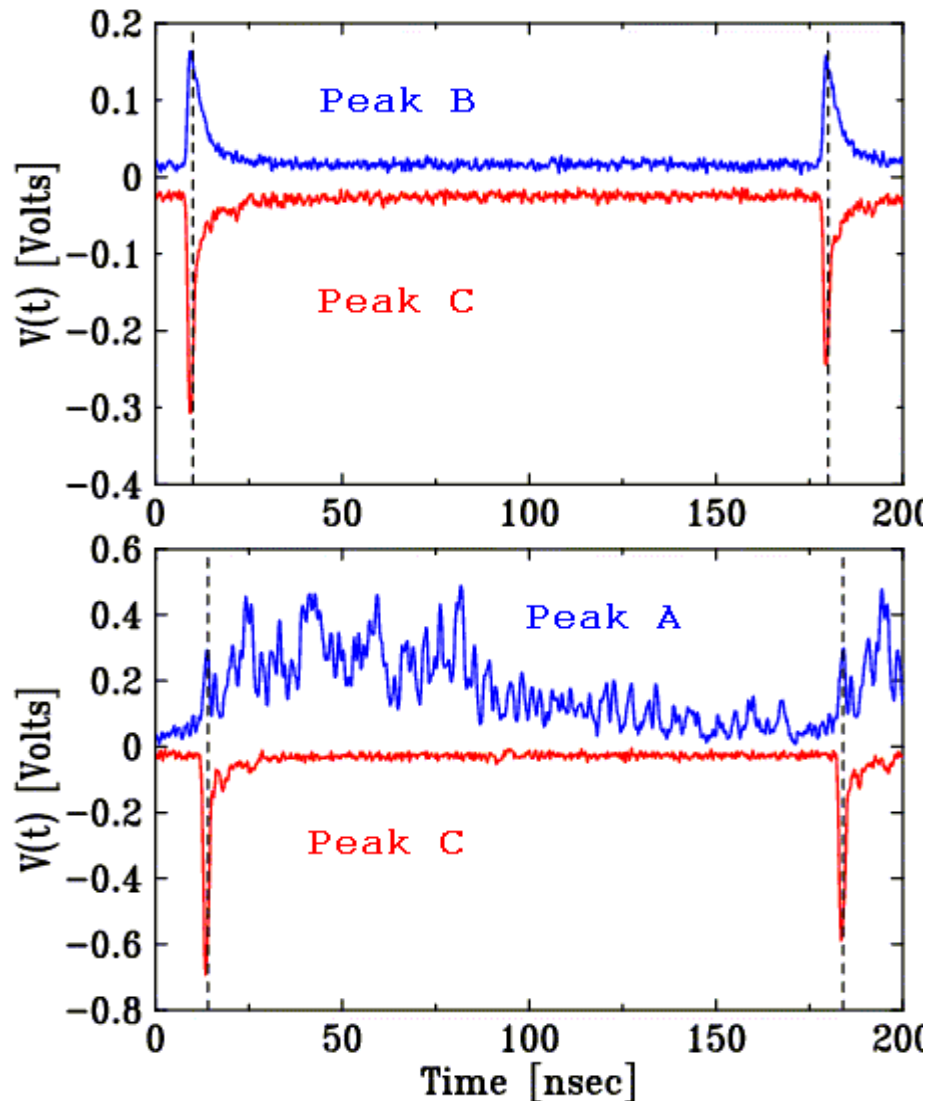
$$f_c \cup \frac{c}{2} \sqrt{\frac{\rho}{h^3}}$$

ρ = bend radius , h = vacuum chamber full height

$f_c \sim 24.1$ GHz for VUV Ring

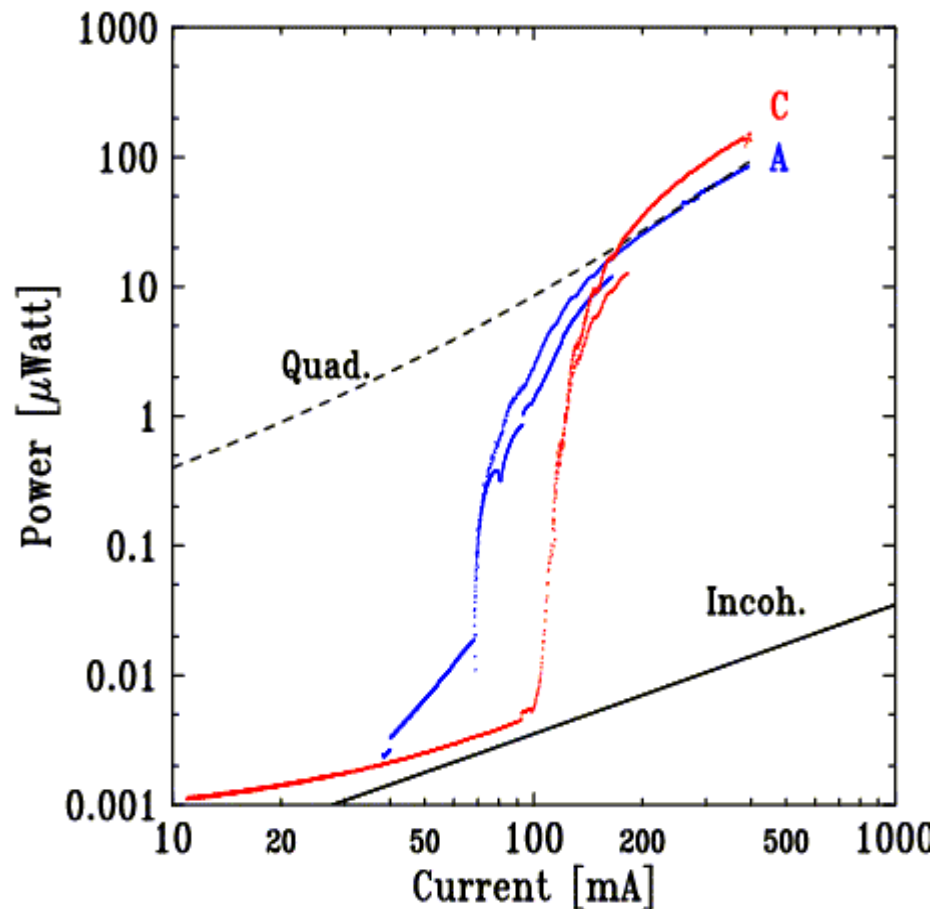
- Coherent **A** peak is major disagreement for shielding
- Coherent **B** peak shows cut-off shifts peak 15->24GHz in agreement with shielding cut-off frequency

Coherent Signal Power for A, B and C Peaks



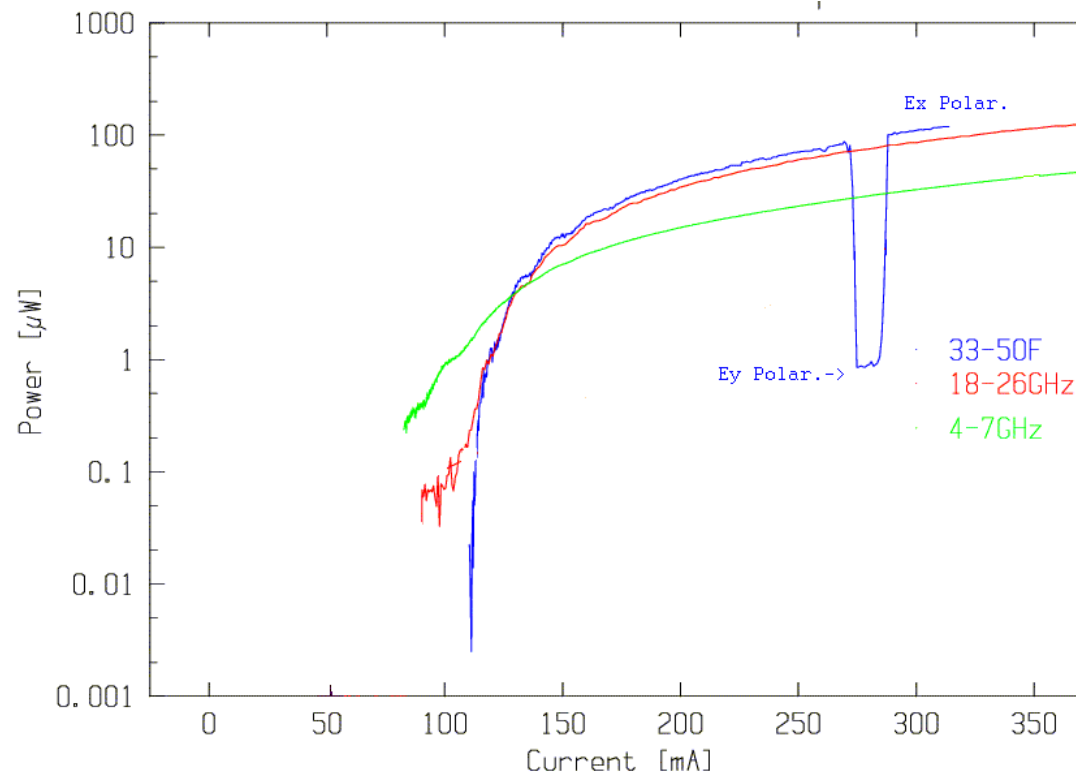
- **B** and **C** are prompt signals from the bunch
- **A** signal 60-80ns wide delayed by ~30-50ns from bunch

Average Power vs Current



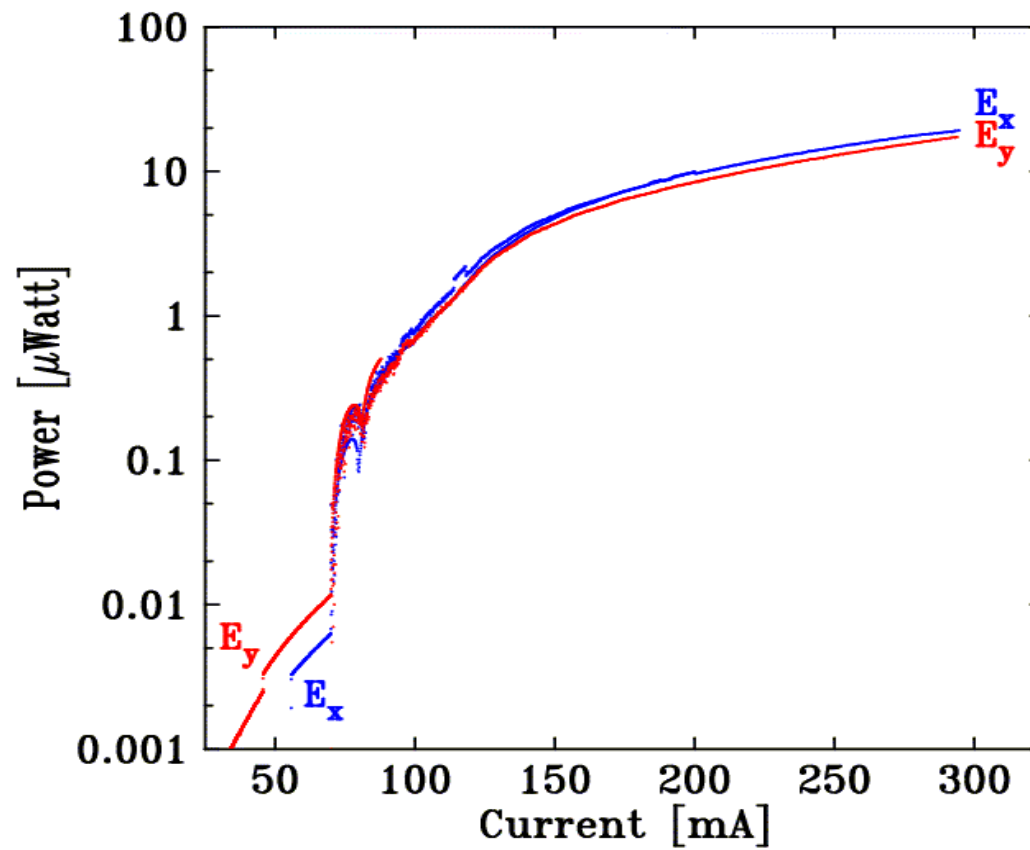
- **C signal linear** below I_t
- **C quadratic** above I_t
- **A signal never linear**
- **A quadratic** above I_t

Above Threshold Power A,B and C

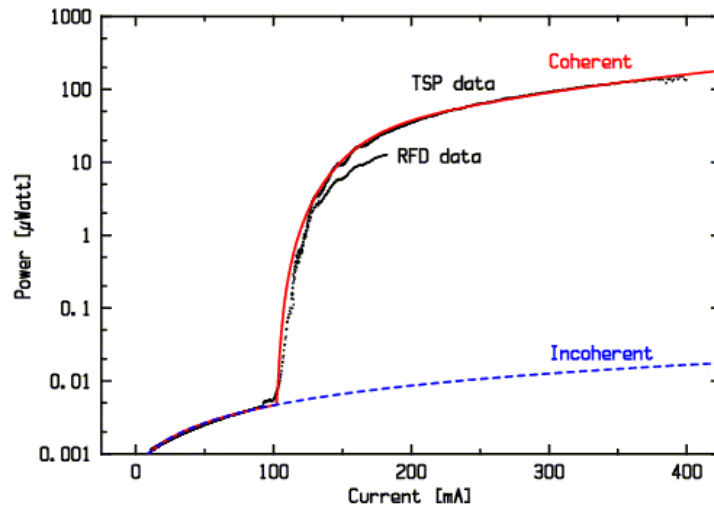


B and C peaks similar linear polarization in the bend plane

A Peak Shows $E_x \sim E_y$ for all I_0



B and C signals show well defined threshold current



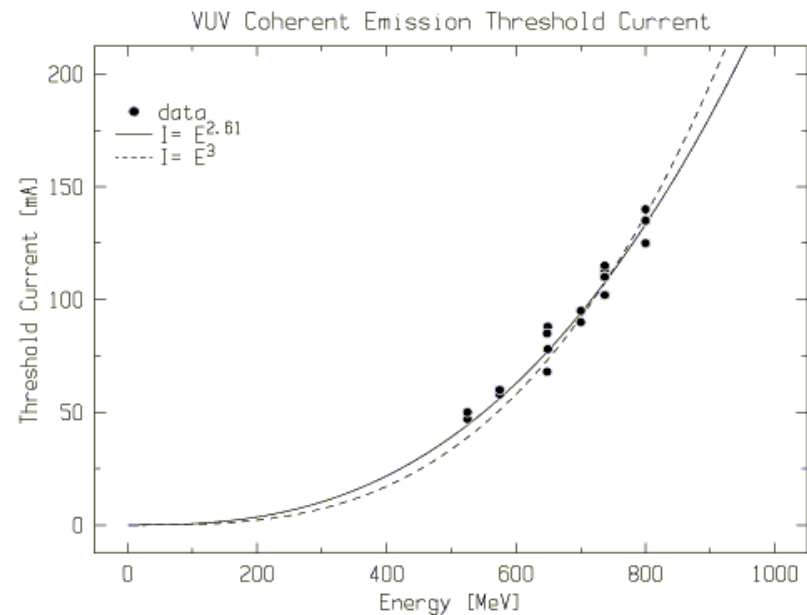
C signal shows $I_t = 103 \pm 2 \text{ mA}$
at $E_0 = 737 \text{ MeV}$ Injection Energy
B signal similar but slower rise at
lower energies

The microwave threshold based on
the Keil-Schnell Criterion

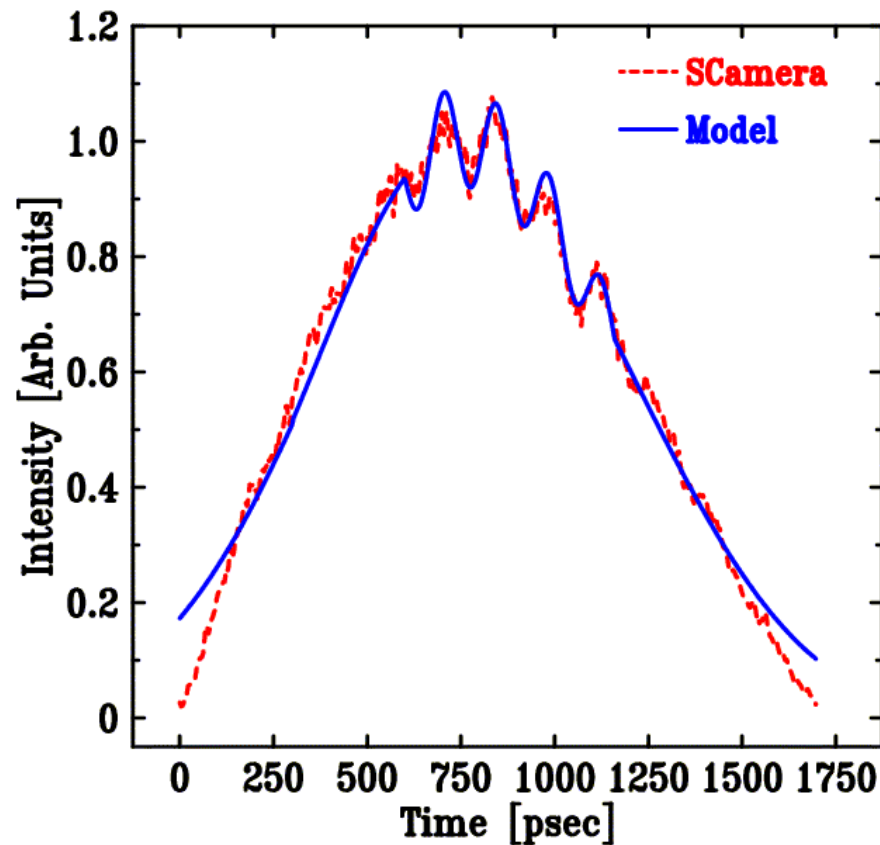
$$I_{th} \propto \frac{\alpha E_o \sigma_\delta^2 \sigma_t}{|Z_{||} / n|}$$

and

$$\sigma_\delta^2 \propto E_o^2, \quad \frac{\sigma_t}{|Z / n|} \propto f(E, I)$$



A Peak Induces Current Modulation above Threshold



**Streak Camera bunch current measurement
Triggered on large A peak signal**

see B. Podobedov PAC'01, p.1921 (2001)

Synchrotron Radiation Power

$$P_{tot}(\omega) = N[1 + N f(\omega)] I_e(\omega) = P_{ISR}(\omega) + P_{CSR}(\omega)$$

where N = number of particles in the bunch

$I_e(\omega)$ is the power spectrum for single electron

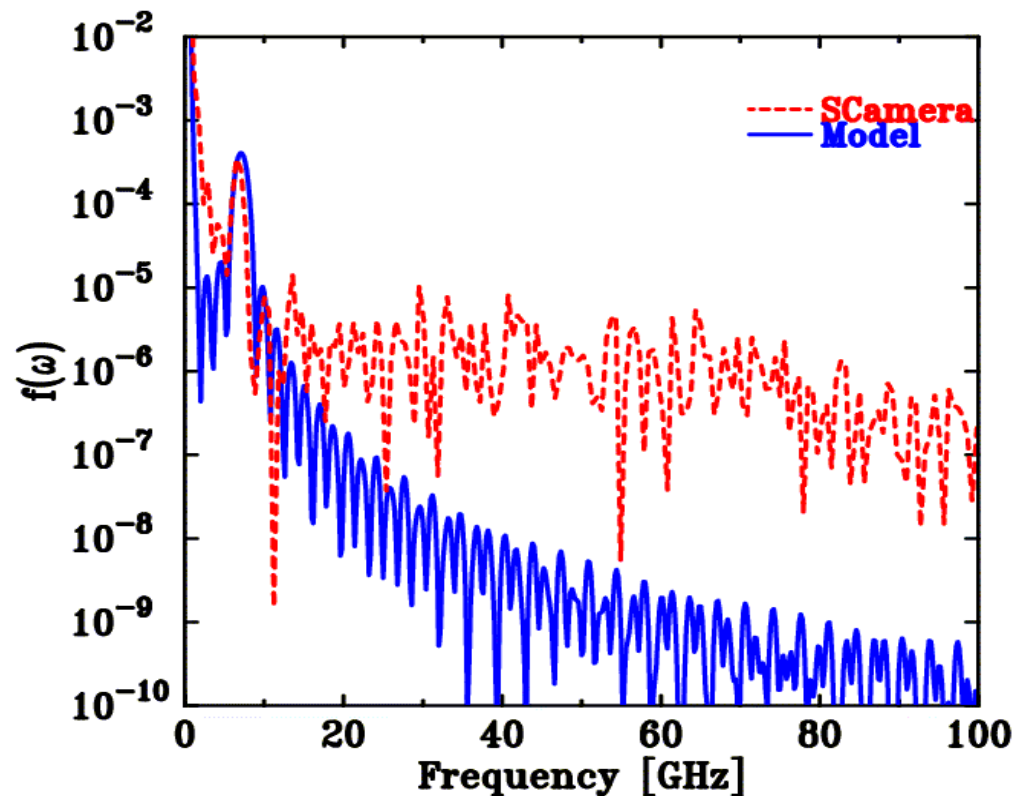
$f(\omega)$ the form factor spectral power density

$$\frac{P_{CSR}(\omega)}{P_{ISR}(\omega)} = N f(\omega) = G(\omega) \quad \text{the Gain or enhancement factor}$$

For VUV bunch length $\sigma \sim 300 \text{ psec}$, $G(\omega) \ll 1$ for all N

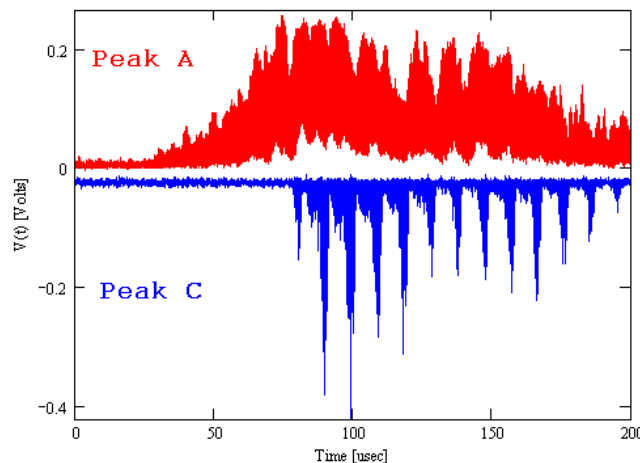
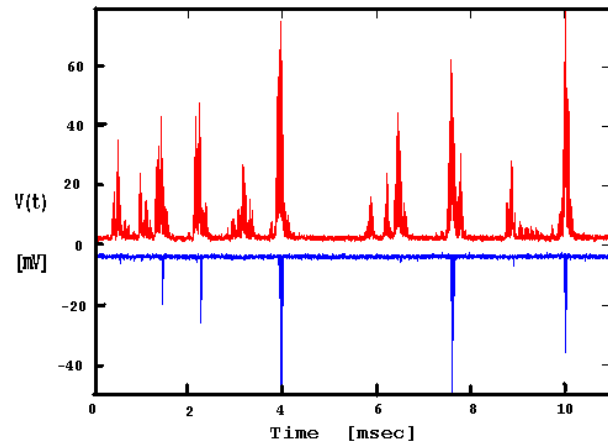
for $I_0 = 100 \text{ mA}$, $N = 1.06 \times 10^{11}$

Form Factor for Measured Current Modulation



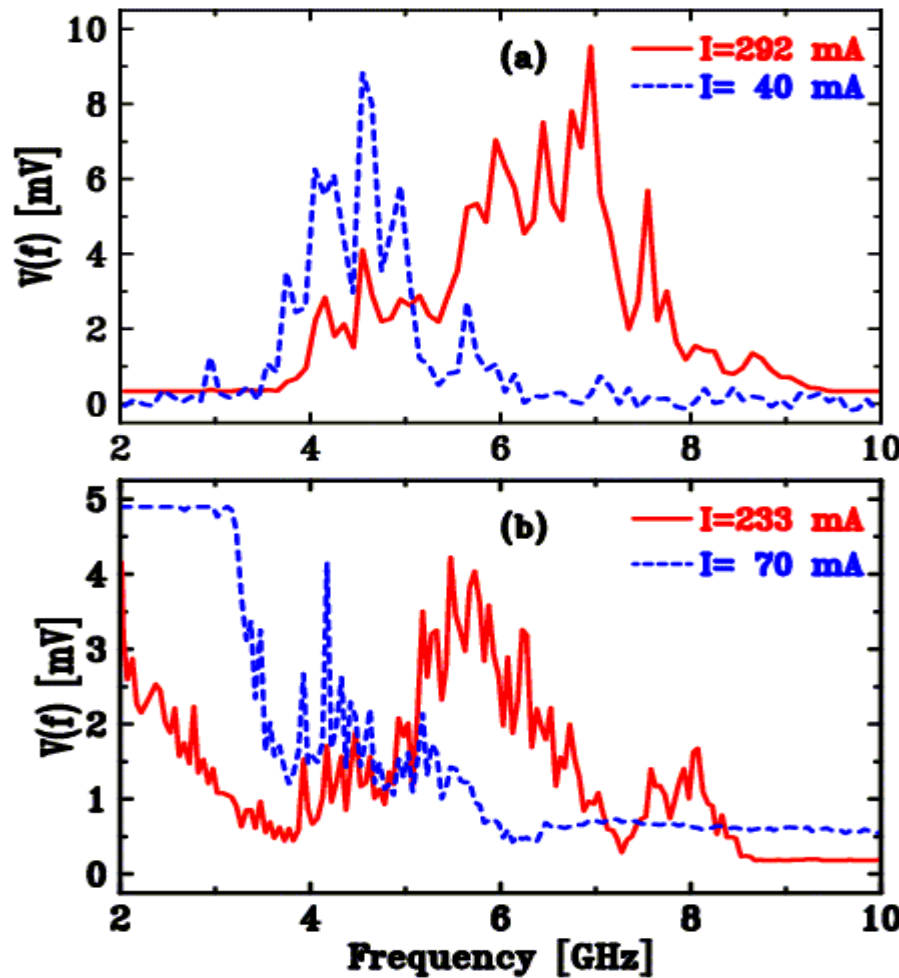
**At 400mA, $f(w)$ $N \sim 4,000$ compared to measured
C signal enhancement of $\sim 9,600$**

Time Structure of Power Bursts



- **C** always with **A** signal but **A** without **C**
- **A** peak leads and is longer than **C** signal
- HF bursts on **C** also on **A** but smaller dynamic range

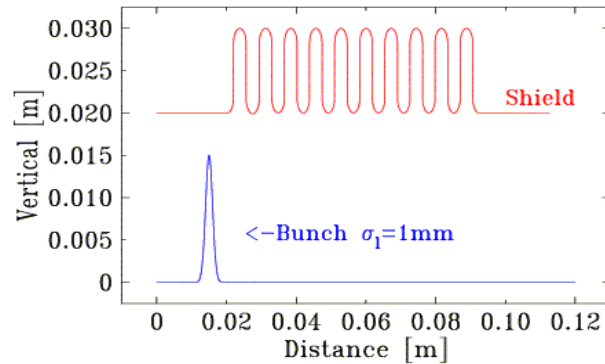
Detailed Microwave and Current Signals



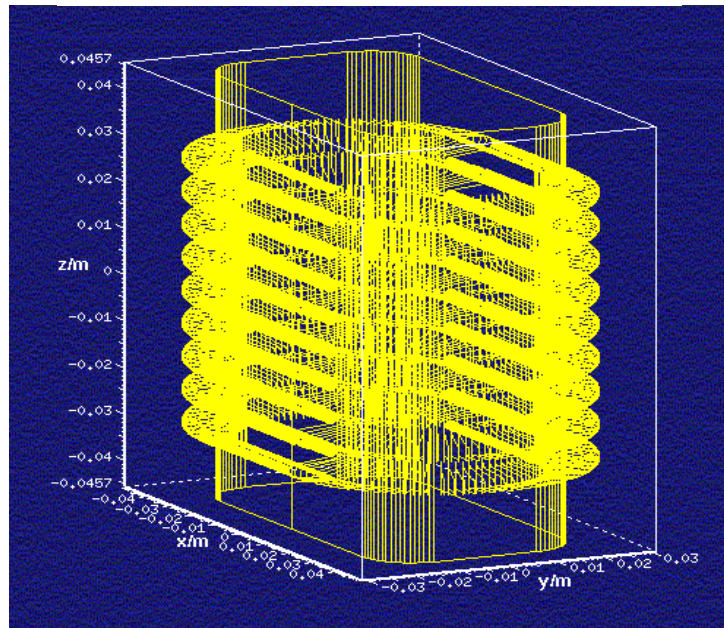
Microwave signal
 $\sim I(f) * Z_b(f)$

BPM signal
 $\sim I(f) * Z_p(f)$

Vacuum Bellows Shield in NSLS Rings

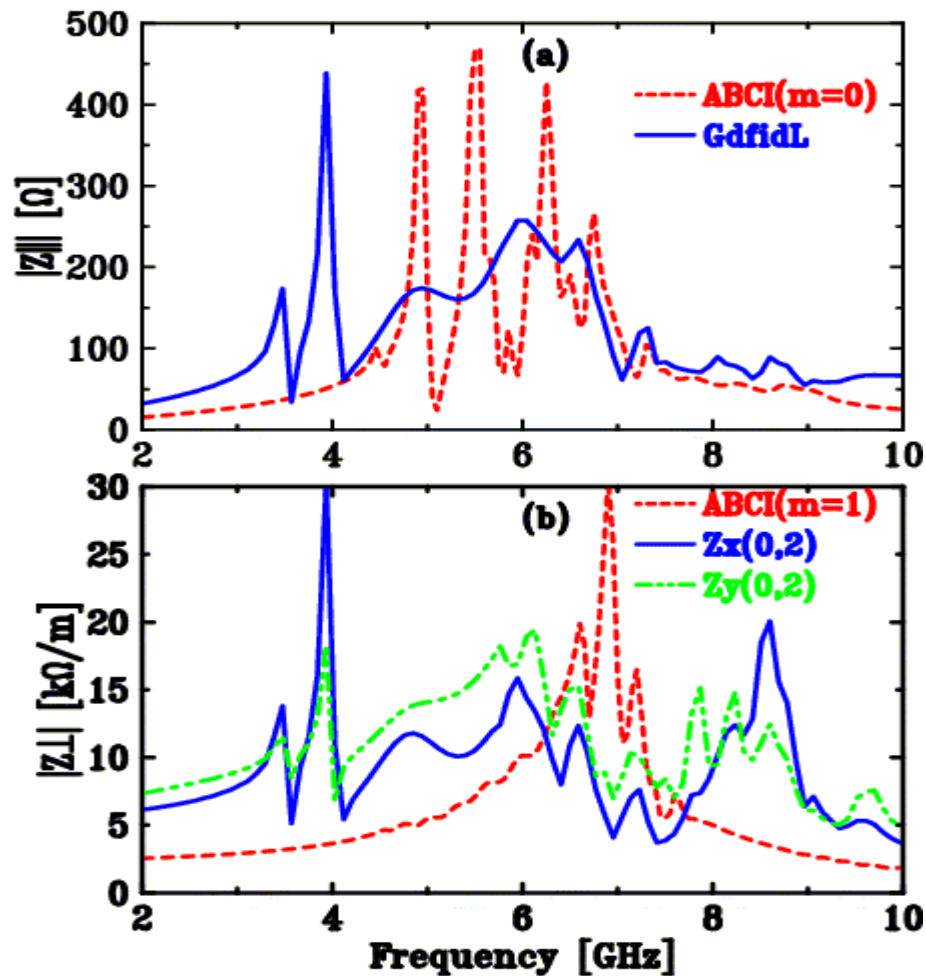


Longitudinal bellows
for ABCI(2-D) with bunch
shape used to calculate
wakefields



Real Bellows shape for
GdfidL (3-D)

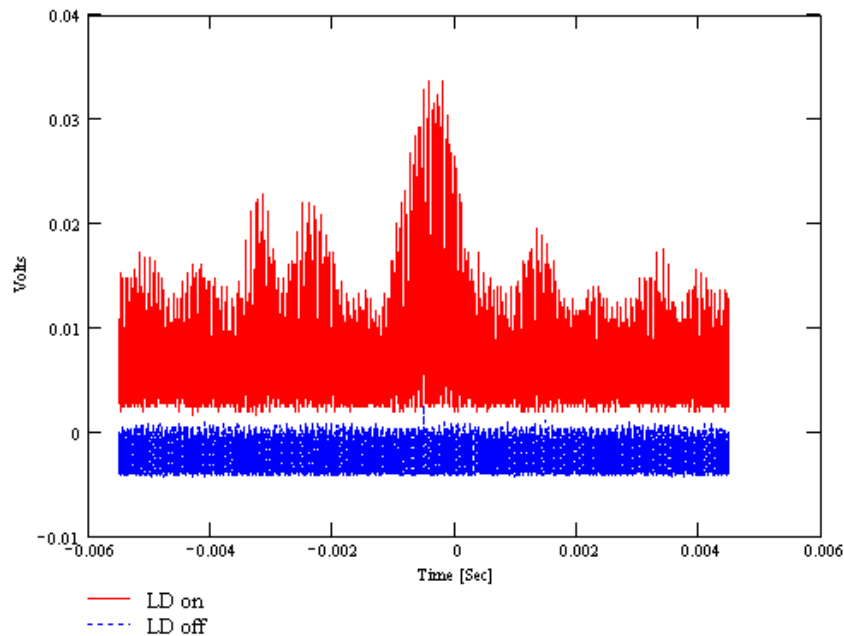
Beam Impedance GdfidL & ABCI



Longitudinal bellows
impedance by
ABCI(2-D) $TM_{0,1}$ $f \sim 5.5$ GHz
GdfidL(3-D) $TM_{1,1}$ $f \sim 4.0$ GHz

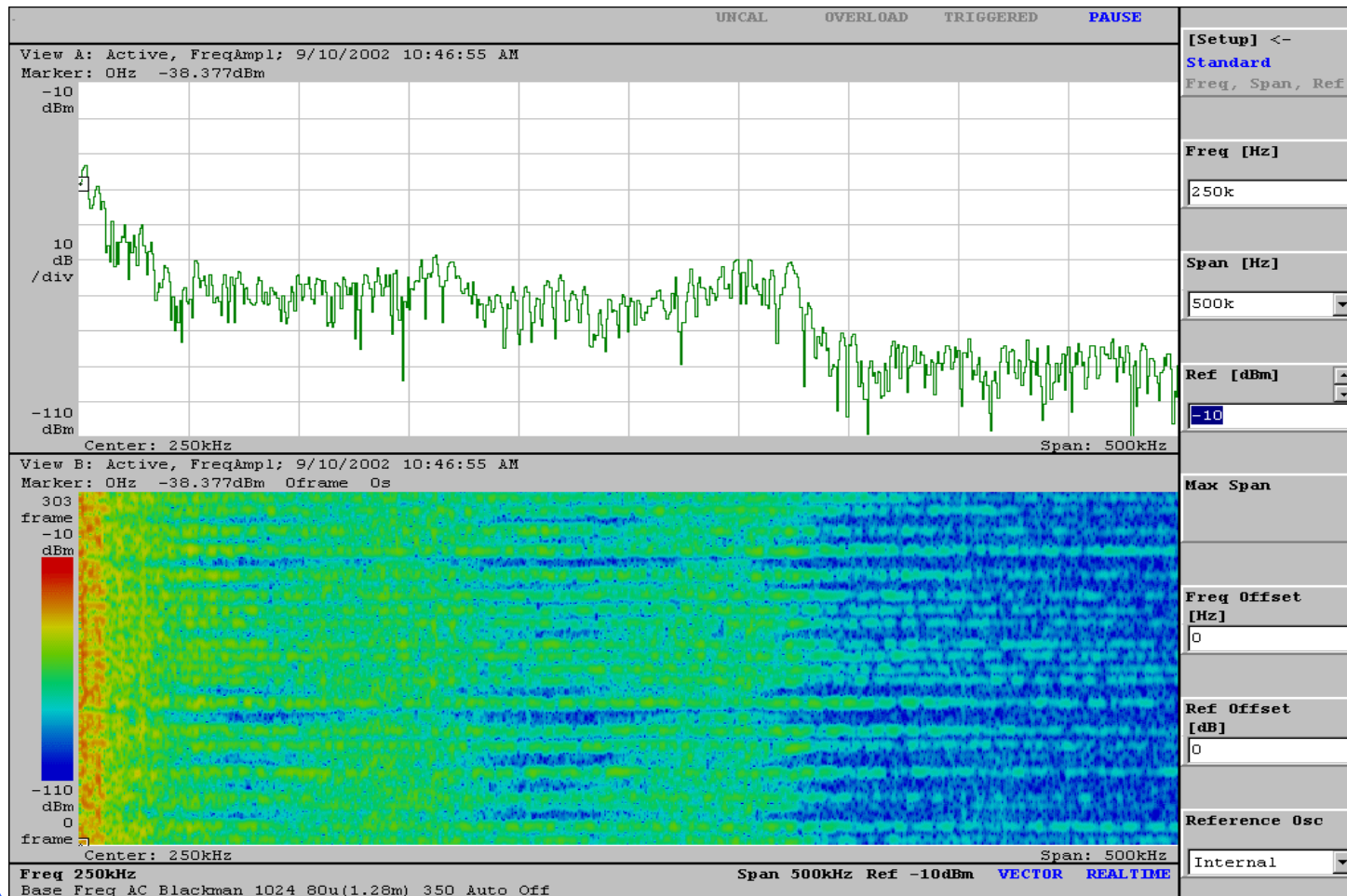
Transverse bellows
impedance by
ABCI($m=1$) and
GdfidL($y=2$ mm)

A Signal Below Threshold



- **Amplified A peak at low current shows similar bursts but with less dynamic range**
- **Long. Damping increases A signal below I_t**

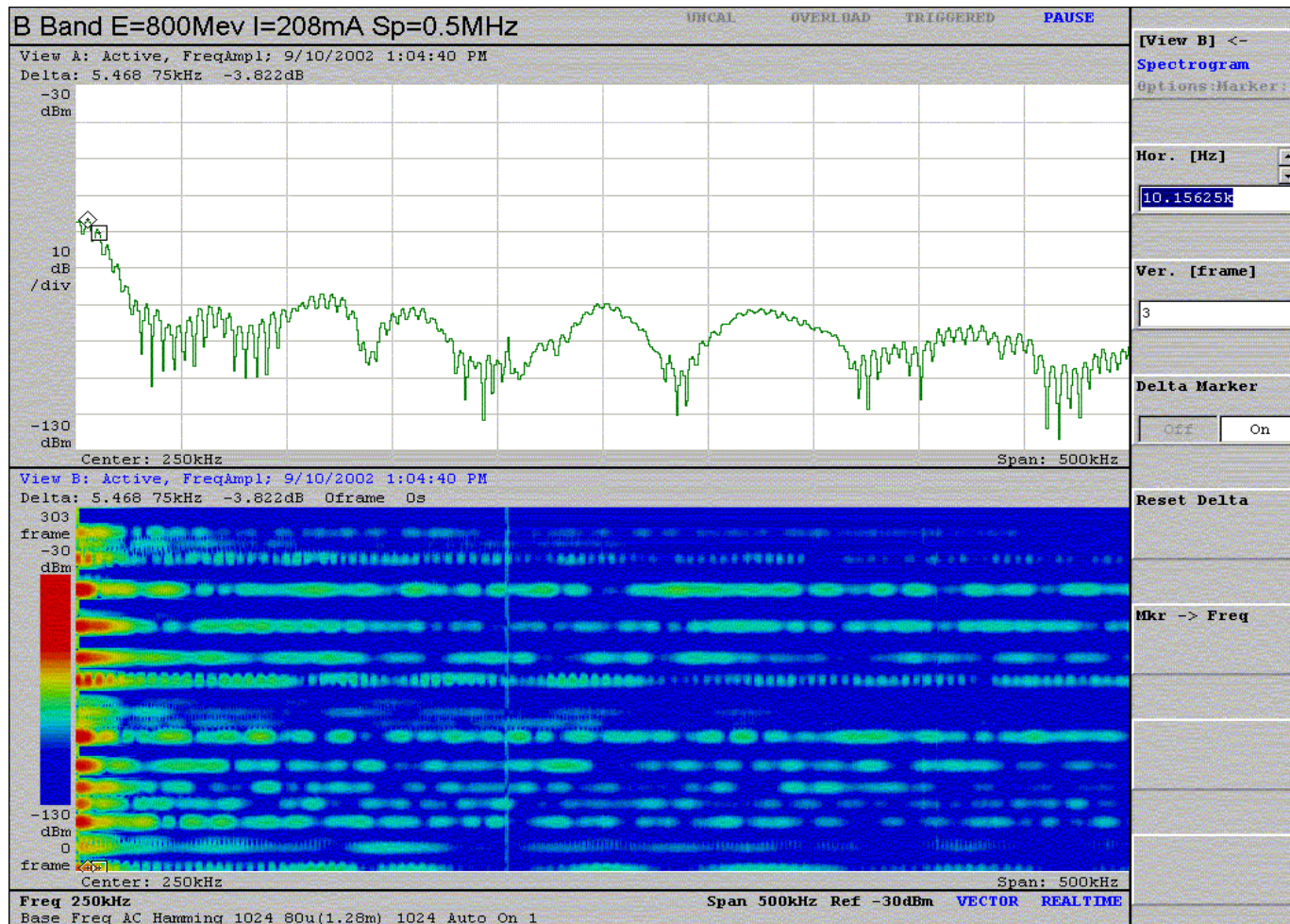
A-Signal Driven by RF Noise



Real Time
Spectral Anal.
Of A-Band
Detected signal

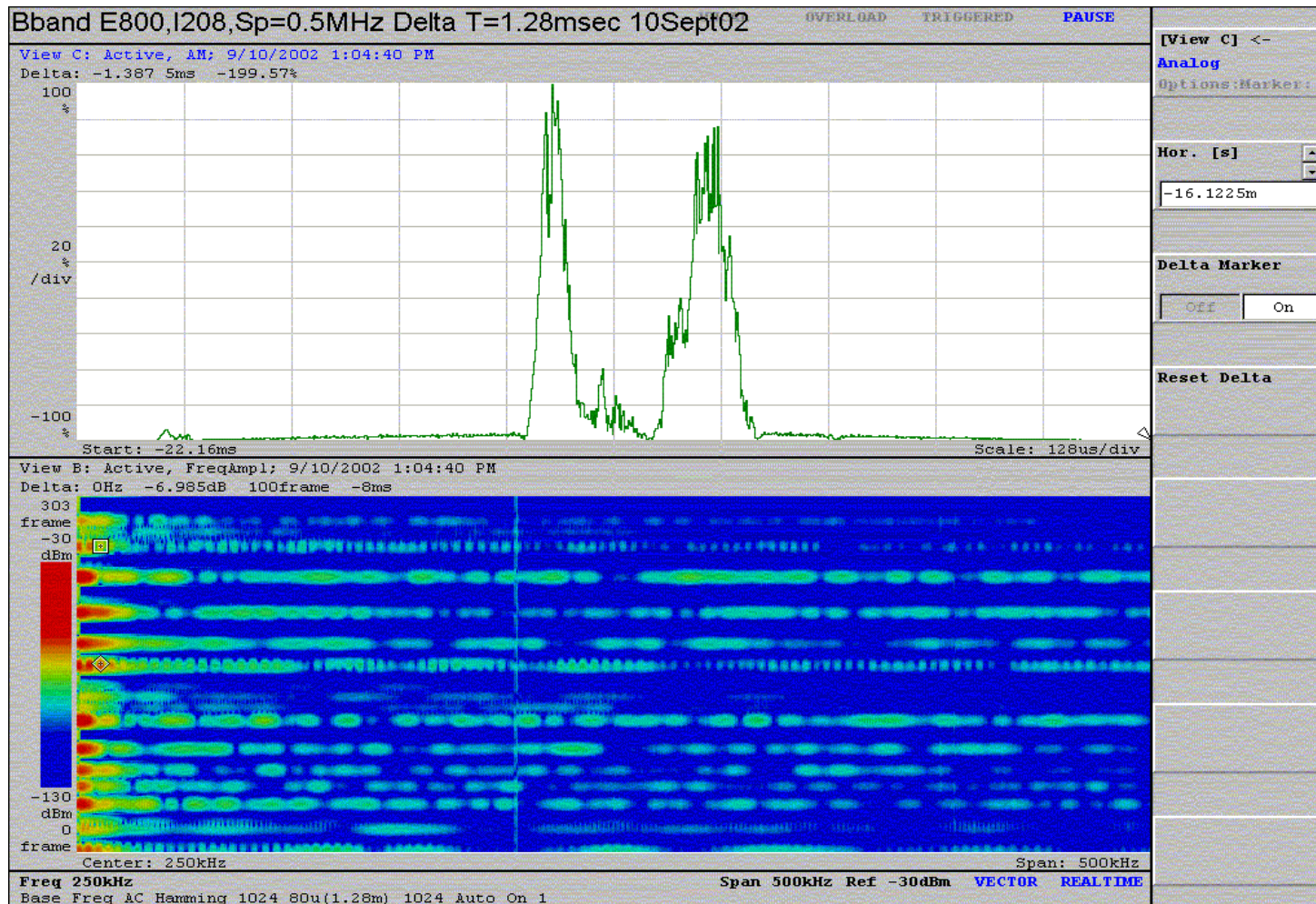
RF Plate noise
at 720 Hz and
harmonics

B-Signal shows similar bursts

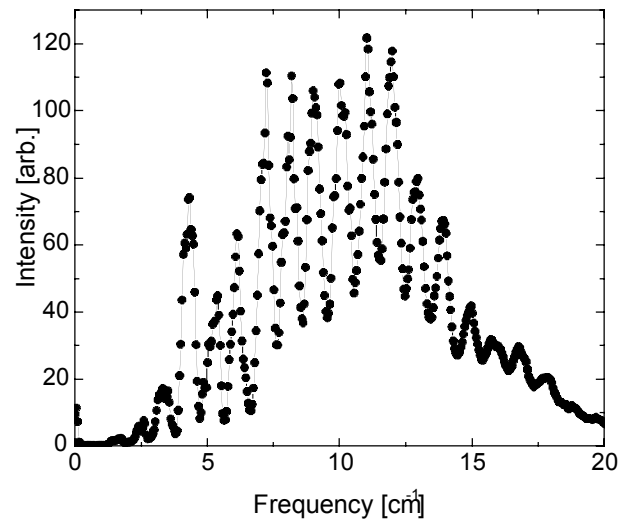


Real Time
Spectral Anal.
Of B-Band
Detected signal

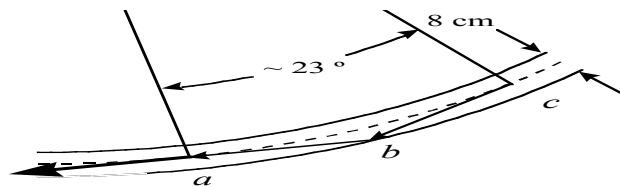
B-Signal shows Time of bursts



Harmonic CSR should be Broadband



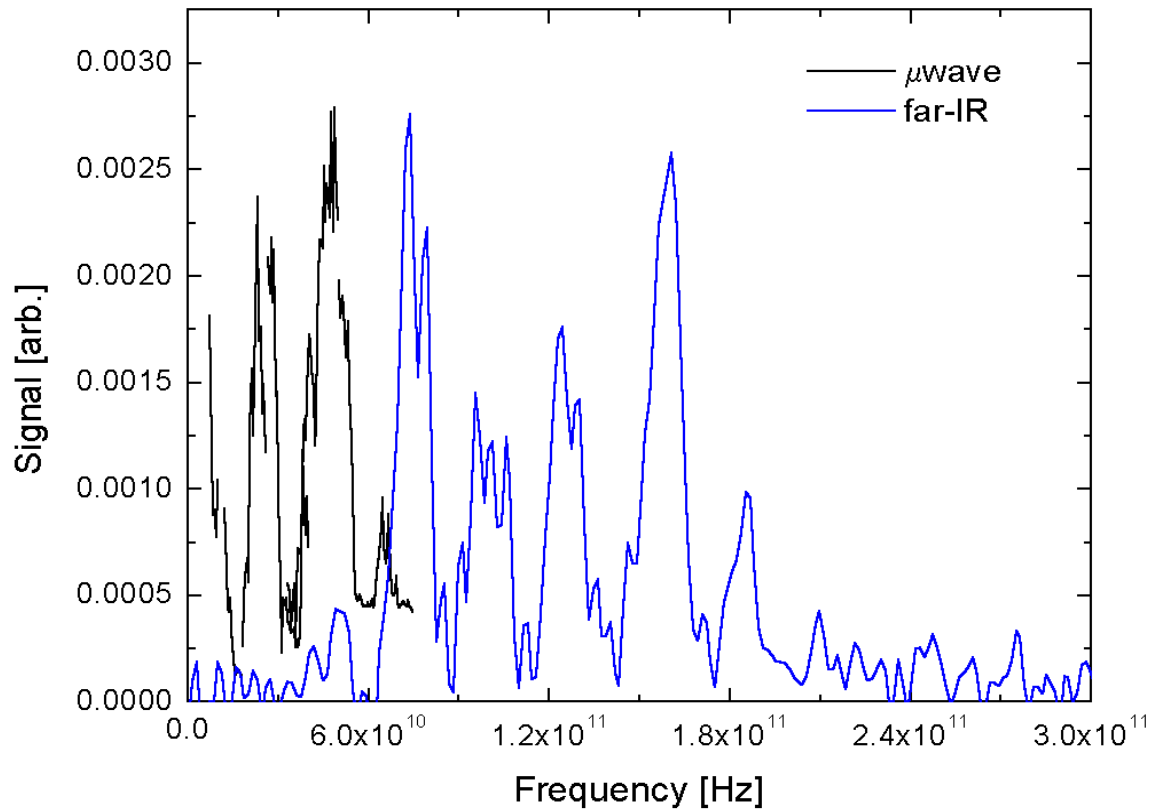
At U12IR ISR shows $dF \sim 1/\text{cm}$ fringe pattern due reflection off vacuum chamber wall.



This should yield peak at 15 and 45 GHz and zero at 30 GHz, without shielding cut-off.

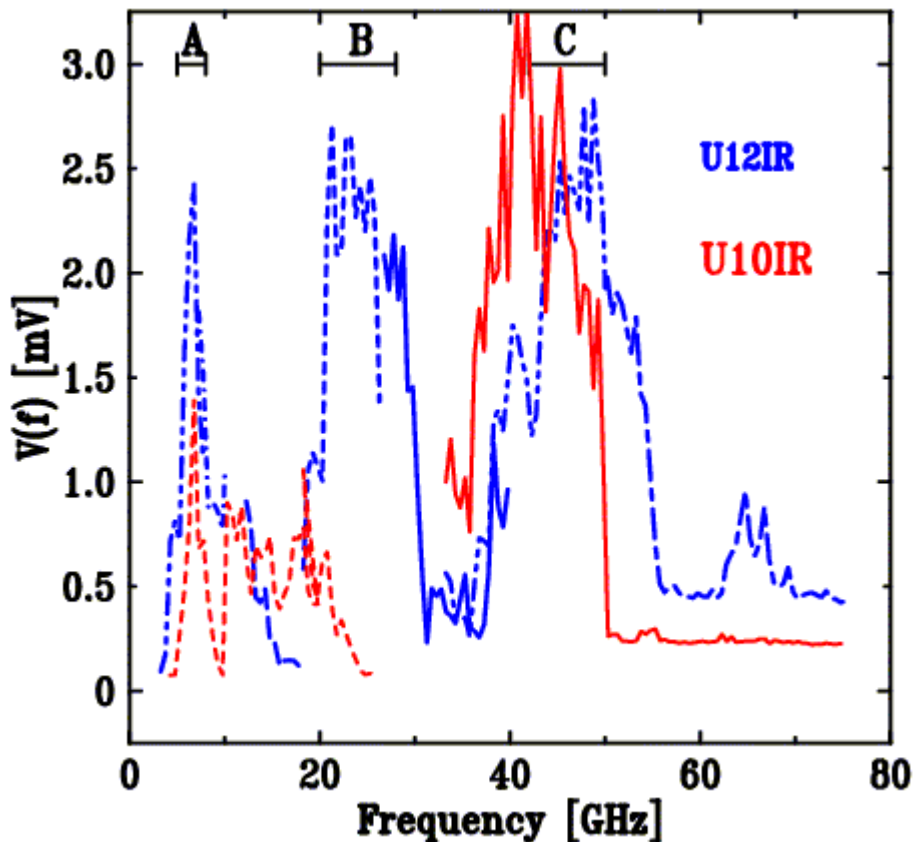
At U10IR dipole bend angle only 20deg. Not enough for this reflection.

FIR CSR Spectral Distribution-200GHz



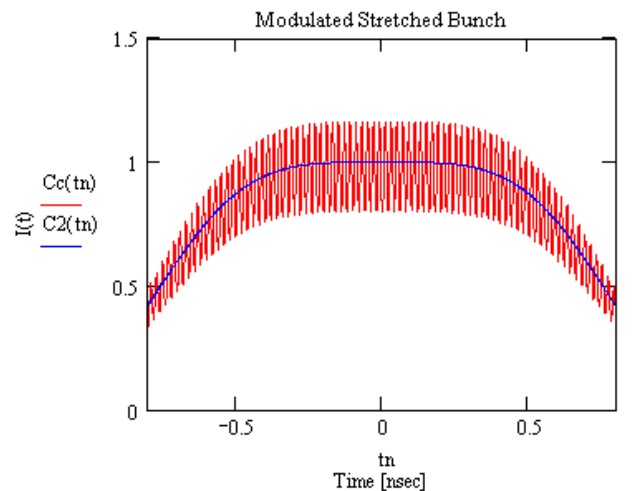
Using different spectrometer shows higher peaks of this fringe pattern.

Spectra above shielding cut-off not identical in all beam lines

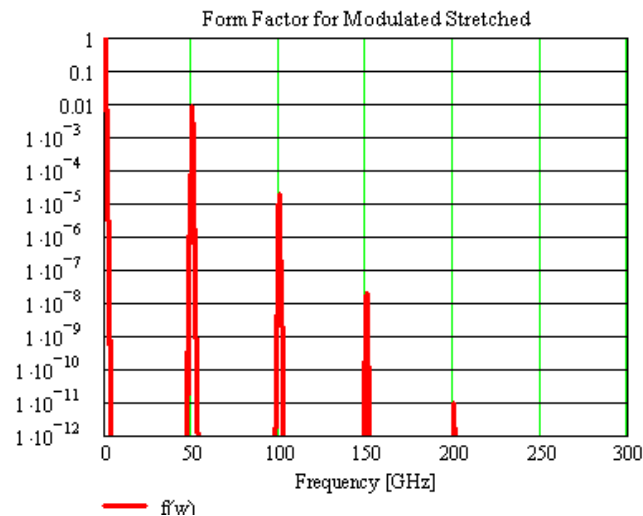


U10IR doesn't allow same
reflection interference
pattern as U12IR due to
lower bend angle
Also smaller vertical aperture
suppresses A signal but B
should not be affected.

Modulation at 50GHz for Stable CSR Emission



With stretched VUV Bunch
only 50 Volts yields 20%
modulation at 50 GHz



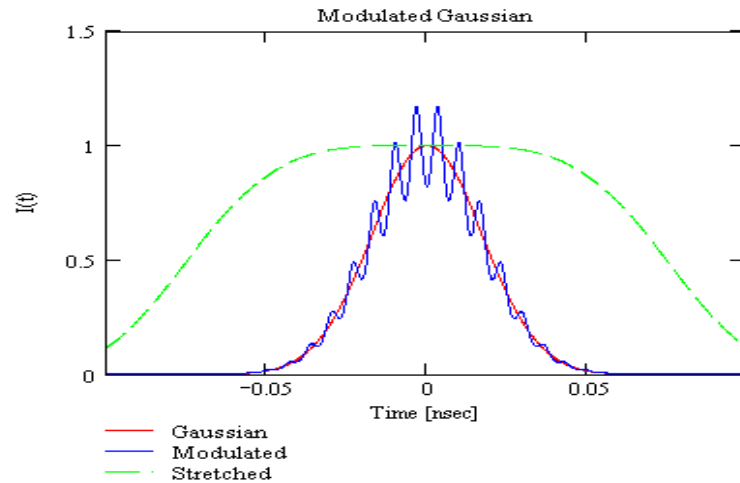
However Gain ~ 1 at 200GHz

This is due to long bunches and
its better to go to higher RF

Need shorter bunches to
increase harmonic range, but
this requires higher modulation
voltage.

500MHz RF System for VUV

F_m=150GHz modulation on 500MHz Gaussian Bunch $\sigma_t=17\text{psec}$

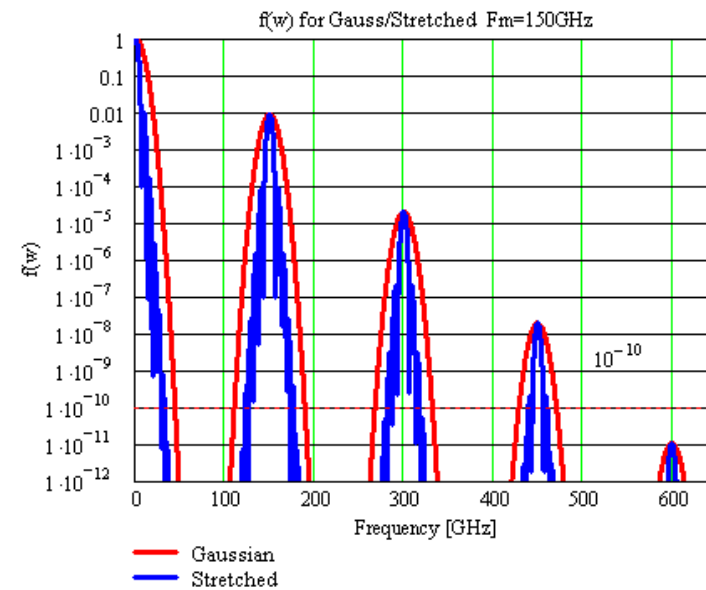


Assuming $f_m = 150\text{GHz}$ and 500V input, then $I_0 \sim 10\text{mA}$ would give

$$N_e \sim 10^{10} \text{ e/bunch}$$

and a Gain ~ 200 up to 450GHz

Replacing 50MHz system with a 500MHz RF system could yield higher frequency CSR but requires higher voltage coupled to beam.



Conclusions and Future Work

- **A** peak is wakefield from beam
 - Above threshold induces modulation on bunch current
- Modulation drives CSR for **B** and **C**
 - Higher frequency modulation in FIR
 - Peak structure from reflections
- FIR beam port yields HF beam properties and impedance for existing vacuum chamber

Conclusions and Future Work

- **Driven modulation could yield higher frequency harmonics up to 4X Fm**
- **Lower voltages needed for 50 MHz RF system and narrower spectral distributions**